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Decontamination and Reuse of Personal Protective Masks and Respirators in Healthcare:

Human-Centered Investigation and Implementation Considerations

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1. Introduction

Face coverings, including surgical/procedural masks, cloth community-made masks and other facial coverings, became an integral part of daily living during the Coronavirus disease 2019 (COVID-19) pandemic. Masks serve as a "source control" for infectious virus that may be present in coughs, sneezes or other respiratory particles (Milton et al., 2013) and offer some protection to the wearer from the virus that causes COVID-19, Severe Acute Respiratory Syndrome coronavirus-2 (SARS-CoV-2) (Chu et al., 2020). During the early days of the pandemic, increased demand for personal protective equipment (PPE) led to shortages in surgical/procedural masks and filtering facepiece respirators (FFRs), including N95 respirators, for healthcare workers (HCWs) (Kamerow, 2020; Ranney et al., 2020). Access to adequate PPE is critical to HCWs' safety at work. For example, front-line HCWs from the United Kingdom (UK) and United States were found to have an increased risk of contracting COVID-19 compared to the general population even after taking into account differences in testing rates between the two groups (Nguyen et al., 2020). Having access to adequate PPE was one of several important factors in HCWs' risk of acquiring COVID-19 (Nguyen et al., 2020), and it has been found to have a protective effect against the development of self-reported burnout among HCWs working during the pandemic (Morgantini et al., 2020).

The safety-critical nature of PPE shortages among HCWs led to research focused on the feasibility of decontaminating and reusing single-use masks and N95 respirators (e.g., Gertsman et al., 2020; Gnatta et al., 2020; O'Hearn et al., 2020a; O'Hearn et al., 2020b; Zorko et al., 2020; Paul et al., 2020; Rodriguez-Martinez et al., 2020; Schumm et al., 2021; Seresirikachorn et al.,

2021). Naturally, the central questions in this line of research are whether decontamination methods destroy the pathogen of interest, as well as whether successfully decontaminated single-use masks perform to the same standard as new (not previously worn) masks. A third critically important question, however, is how wearing decontaminated single-use masks affects the human performing the work. HCWs need to feel safe, supported, adequately trained and able to perform their job duties (Kisely et al., 2020; Brooks et al., 2018), and it is therefore essential to ensure that the introduction of decontaminated masks to the work force – should such masks be required in the case of a PPE shortage – is not only safe, but also minimally disruptive to those who must wear them. Human factors and ergonomics knowledge and methods can assist in such undertakings (Gurses et al., 2020).

Overall, our goal was to focus on 'the human factor' in mask decontamination and reuse to inform the development and implementation of mask decontamination and reuse systems in healthcare settings during critical PPE mask supply chain disruptions and shortages. Research in this area (and particularly, within the context of COVID-19) appears to be limited. Notably, Nemeth and colleagues (2020) interviewed and surveyed HCWs and other stakeholders to understand the human-centered and logistical considerations involved in implementing a system to decontaminate FFRs for reuse during a hypothetical influenza pandemic. Our study considers a broader variety of masks and decontamination methods, and it differs in that HCWs' concerns were captured during an actual pandemic at a time when the potential for PPE shortages posed a tangible threat to their routine work. We recruited healthcare workers for mask testing and aimed to attain a better understanding of HCW's perceptions of decontaminated masks, with an emphasis on the identification of discomfort, potential impediments to performance, or any

reservations related to using decontaminated masks on the front lines. Our research is relevant not only to the current pandemic, but also to future respiratory virus pandemics.

2. Methods

Our study is an extension of the Development of Methods for Mask and N95 Decontamination (DeMaND) study (Lendvay et al., 2021), and it was approved by the University of Calgary Conjoint Health Research Ethics Board (CHREB).

2.1 Participants

There were two study arms, and each had a set of inclusion criteria. Doctors, nurses and respiratory therapists working in two hospitals in a major city in Alberta, Canada, who self-reported previous fit-testing and regular use of N95 respirators, and who passed a baseline fit test with their assigned mask (see *2.3.1 N95 respirator arm*, below), were eligible for the study arm focused on N95 respirators. Individuals working in these roles, as well as other HCWs working in the two hospitals, were eligible for the second arm of the study focused on surgical/procedural and cloth "community" masks. Participants in both arms of the study were targeted due to their high-frequency use of N95 respirators and/or surgical/procedural masks at the front lines of patient care.

Participants were recruited and enrolled over the summer and fall months of 2020. Initially, participant recruitment was executed via personal invitations made through the research team's professional networks and mass emails distributed through unit email lists. However, recruitment for two of the three types N95 respirators provided for the study (i.e., the 3M 1860 and the Halyard Duckbill) required a more tailored approach. Because there were no known eligible HCWs previously fit-tested to the 3M 1860 as part of their work, individuals who were known to fit either the 3M 8110S or the 3M 8210 were targeted for preliminary fit-tests with the

3M 1860. These individuals were either self-referred following general or targeted mass emails (i.e., to lists of individuals known to fit the 3M 8110S) or through personal invitation by members of the research team. A similar approach was taken with the Halyard Duckbill.

2.2 Materials

Masks and decontamination methods. Three models of N95 respirators were used in the N95 respirator arm of the study. These were the 3M 1870+ panel respirator (i.e., referred to in this study as the "3M 1870+"), the 3M 1860 half-sphere respirator (i.e., the "3M 1860"), and the Halyard Fluidshield 46727 duckbill respirator (i.e., the "Halyard Duckbill"). Two types of surgical/procedural masks, and the Colorado cloth "community" mask, comprised the three varieties of masks in the non-N95 mask arm of the study. The two surgical/procedural masks were the generic EN 14683 Type II medical mask (i.e., the "WHO surgical/procedural mask") and the Halyard ASTM F2100 Level 2 procedure mask (i.e., the "Halyard surgical/procedural mask"). Together, these six varieties of masks (see Figure 1, below), which were part of the WHO stockpile, were allocated to the University of Calgary for the purposes of the DeMaND study. The decontamination methods applied to the masks included vaporized hydrogen peroxide, methylene blue and UV light, and dry heat. For more information on these masks and decontamination methods, see Lendvay et al. (2021).

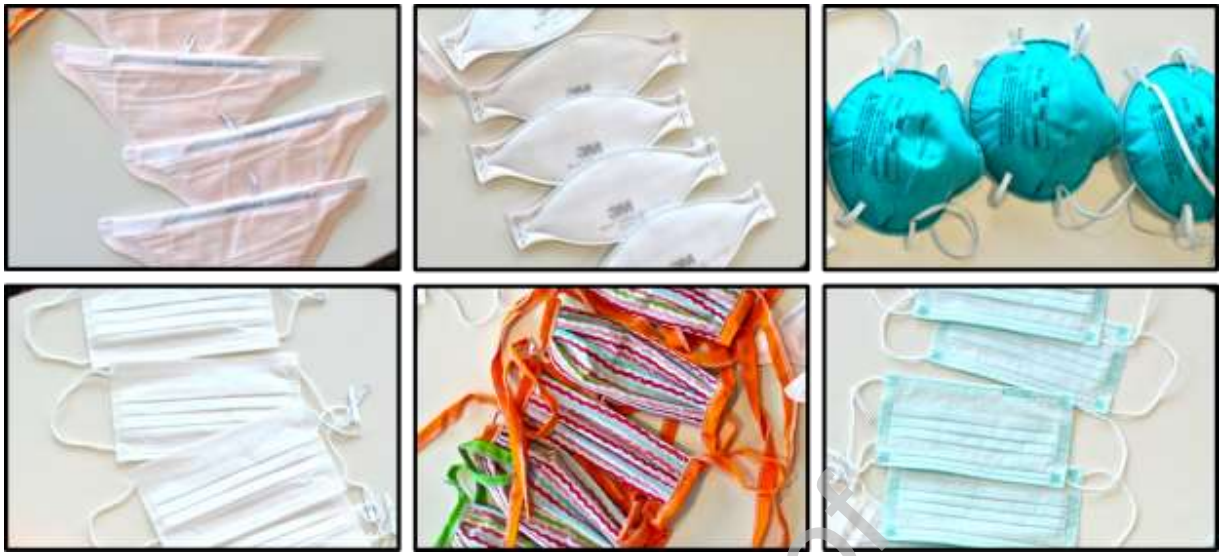

Figure 1. Examples of masks included in the study. Top row, from left: Halyard Duckbill FFR; 3M 1870+ FFR; 3M 1860 FFR. Bottom row, from left: Halyard surgical/procedural mask; Colorado cloth "community" mask; WHO surgical/procedural mask.

Survey. We created a survey, to be completed on an electronic tablet, comprised of three major sections: visual inspection, comfort assessment, and a general questionnaire.

Visual Inspection. Before each fit test with a decontaminated mask, participants completed a visual inspection. This inspection was based on recommendations for inspecting respirators before wear (Government of Canada, n.d.). Participants assigned respirators were asked to assess if the mask was free from "visible signs of damage", had "intact" straps and provided "a proper seal" (Government of Canada, n.d.). Participants assigned non-N95 masks were asked the first two questions, as well as whether the mask "fit properly" (since non-N95 masks do not form seals). Participants' verbal responses were entered into the electronic survey by the lead author (SS).

Comfort Assessment. Following a successful N95 respirator fit-test, or a period of wearing the non-N95 mask, participants completed a comfort assessment. Many of the items

appearing in the comfort assessment were adapted from items in the Canadian Standards Association (B.2.3.3/C.2.3.3 of CAN/CSA-Z94.4-18; CSA Group, 2018). Briefly, participants were asked to complete a series of short head movements (i.e., nodding, tilting, turning, shaking) and facial movements (i.e., opening and closing the mouth, moving the jaw, smiling, frowning) and asked if they noticed any difference between the decontaminated mask and an untreated (i.e., new and not previously worn) control mask in terms of how the mask sat on the nose and chin; seeing and speaking abilities (including accommodation of glasses, if applicable); and, pressure, stability, texture, strap tension and odor. Participants were also asked to rate their overall comfort on a four-point scale and were asked if there was a specific area of the face that felt less comfortable compared to the untreated mask, including the nose, chin, cheeks, forehead, back of the head, ears or other. Participants' verbal responses were entered into their electronic survey by SS.

General Questionnaire. The goal of the questionnaire was to elucidate areas where training, communication and trust in PPE might be enhanced. These three factors were some of those identified by Kisely et al. (2012) as affecting psychological outcomes among HCWs during "emerging virus" outbreaks, including COVID-19. Ultimately, the questionnaire contained items thematically related to (1) protection from pathogens, (2) concerns about contamination, (3) endorsements, and (4) trust. Individual questionnaire items appear in Tables 2 and 3 in *Results*, below. Participants were handed the tablet to add their responses directly into the electronic survey.

2.3 Procedure

Participants were assigned to complete the study with one of six mask variety assignments in a non-randomized fashion. Our goal was to allocate participants to either a non-

N95 mask or to an N95 respirator that they were either known to fit or that they had a good chance of fitting, such that masks made available for use in the study were used efficiently with minimal waste.

First, participants were assigned to either the N95 respirator arm or the non-N95 mask arm based on inclusion criteria for the two arms, their fit-test history with different N95 respirators as part of their work (or lack thereof), their face shape (which helped inform which N95 respirators may or may not fit the participant in the N95 respirator arm of the study), preliminary fit test results, and the remaining masks available for use in the study. Within each arm, participants were assigned to one of three respirator varieties (i.e., either the 3M 1870+, the 3M 1860, or the Halyard Duckbill N95 respirator in the N95 respirator arm; or, either the WHO surgical/procedural mask, the Halyard surgical/procedural mask, or the Colorado community cloth mask in the non-N95 mask arm). This resulted in six groups of five participants each (i.e., five participants per mask variety across the two arms of the study). Participants then received four masks of that variety – one untreated mask, one treated with methylene blue and UV light, one treated with vaporized hydrogen peroxide, and one treated with dry heat – to use to complete the study. Crossing each of the six mask varieties with each of the three decontamination methods, plus the baseline (untreated) mask, yielded 24 unique conditions. Given the constraints of our small mask supply, and our goal of collecting feedback from at least five participants per study condition (e.g., as would be good practice in a usability study; Nielsen, 2000) we elected to recruit 30 participants to interact with 120 masks.

2.3.1 N95 respirator arm. Upon arrival, participants who were known to fit the N95 respirator to which they were allocated completed eligibility screening, signed consent forms, and were enrolled in the study with a random ID number. Participants then completed a baseline

quantitative fit test based on Occupational Safety and Health Administration (OSHA) standards with the untreated mask (OSHA, 2004). All quantitative fit tests in this arm of the study were conducted with a PortaCount® Pro+ 8038 (TSI Inc., Shoreview, MN, USA) machine and recorded as either passes or failures. If the baseline fit test was successful, the participant continued, and if it was unsuccessful, the study session stopped. When the latter occurred, and non-N95 masks were available for testing, eligible individuals were invited to enroll in the non-N95 mask arm and continue their session with a non-N95 mask instead.

Participants who had *not* been previously fit-tested to the respirator to which they had been assigned (i.e., as part of their normal work at the hospital) completed a preliminary fit-test with that respirator. If participants were found to fit that respirator, they enrolled in the N95 respirator arm of the study with that respirator, and their preliminary fit-test served as their baseline. Again, if they were found not to fit the respirator, eligible individuals were invited to enroll in the non-N95 mask arm instead.

Following a successful fit-test with the untreated respirator, participants completed three more PortaCount fit tests with the three decontaminated respirators in a random order. This randomization was generated automatically within the survey software (i.e., Qualtrics). Before each fit test with a decontaminated respirator, a visual inspection was conducted. If the fit test was successful, participants completed a comfort assessment for that mask. If it was not successful, the comfort assessment was skipped. Finally, participants were provided with all the respirators with which they were successfully fit-tested and completed a general questionnaire. Upon completion of the N95 respirator arm, participants were debriefed, thanked for their time, and provided with a gift card to a local coffee shop (valued at $10) and a bagged lunch.

2.3.2 Non-N95 mask arm. The procedure for the non-N95 mask arm of the study was similar to that of the N95 respirator arm. However, because fit-testing is not applicable to surgical/procedural and community cloth masks, which do not form seals, these tests were not conducted. Instead, participants simply tried on and wore the surgical/procedural and community cloth masks for short periods.

Upon arrival, participants completed eligibility screening, signed consent forms, and were enrolled in the study with a random ID number. After interacting with an untreated mask, participants interacted with three decontaminated masks in a random order generated by the survey software. Before each trial with a mask (including the baseline mask), participants completed the same visual inspection as in the N95 respirator arm. Similarly, after each trial (including that with the baseline mask), participants completed the same comfort assessment as in the N95 respirator arm. Following trials with all masks, participants completed the same general questionnaire as in the N95 respirator arm. Upon completion of the non-N95 mask arm, participants were debriefed, thanked for their time, and provided with a gift card to a local coffee shop (valued at $10).

2.4 Analysis

The survey collected both quantitative and qualitative data. From quantitative data, we generated descriptive statistics such as counts, means, standard deviations, and ranges, as applicable. We did not conduct any formal statistical tests. Qualitative data (e.g., open-ended responses to survey questions) were distilled into simple summaries and themes.

3. Results

Thirty participants enrolled in and completed the study. Of these, fifteen participants successfully completed the N95 respirator arm of the study, with five participants assigned to

each of the three N95 respirators (i.e., 3M 1870+, 3M 1860, Halyard Duckbill). Three nurses, one doctor and one respiratory therapist completed the study with a 3M 1870+ respirator; three nurses, one doctor and one respiratory therapist completed the study with a 3M 1860 respirator; and, two nurses, two respiratory therapists and one doctor completed the study with the Halyard Duckbill respirator. Additional participants who were initially assigned to an N95 respirator but failed their baseline fit test were excluded from the N95 respirator arm of the study but invited to participate in the non-N95 mask arm instead. Of those asked to participate in the non-N95 mask arm due to baseline fit test failures, all agreed to do so, and all successfully completed that arm of the study.

Fifteen participants completed the non-N95 mask arm of the study. Five 'other' participants (i.e., infection prevention and control staff) used the Halyard surgical/procedural mask; three doctors and two nurses used the WHO surgical/procedural mask; and, two doctors and three nurses used the Colorado cloth mask.

3.1 Visual inspection. The results of the visual inspection are reported in Table 1. Most decontaminated masks were judged to be free of damage, to have their straps intact, and to fit properly. Notably, fit issues were common with the Colorado cloth masks. It is difficult to assess how much of the variability in fit with the Colorado masks was attributable to differences in construction during the manufacturing process versus the effects of the different decontamination treatments.

Table 1. Proportion of masks judged to have visible signs of damage, intact straps, and proper seal or fit during visual check.

	Visible Signs of Damage	Intact Straps	Proper Seal/Fit
Vaporized Hydrogen Peroxide			
3M 1870+ FFR	0/5	5/5	5/5
3M 1860 FFR	0/5	5/5	5/5
Halyard Duckbill FFR	0/5	5/5	5/5
WHO S/P Mask	0/5	5/5	5/5
Halyard S/P Mask	0/5	5/5	5/5
Colorado Cloth Mask	-	-	-
Methylene Blue + UV Light			
3M 1870+ FFR	0/5	5/5	5/5
3M 1860 FFR	0/5	5/5	5/5
Halyard Duckbill FFR	0/5	5/5	5/5
WHO S/P Mask	0/5	5/5	5/5
Halyard S/P Mask	0/5	5/5	5/5
Colorado Cloth Mask	0/5	5/5	**3/5**
Dry Heat			
3M 1870+ FFR	**1/5**	5/5	5/5
3M 1860 FFR	0/5	5/5	5/5
Halyard Duckbill FFR	0/5	5/5	5/5
WHO S/P Mask	0/5	5/5	5/5
Halyard S/P Mask	0/5	5/5	5/5
Colorado Cloth Mask	**1/5**	5/5	**3/5**

Visual assessments of respirators did not always correspond with a proper fit. Although no issues were identified during their visual inspection, one of the five 3M 1870+ respirators, one of the five 3M 1860 respirators, and four of the five Halyard Duckbill respirators treated with vaporized hydrogen peroxide failed the PortaCount fit test. Similarly, one of the five 3M 1870+ respirators, three of the five 3M 1860 respirators, and one of the five Halyard Duckbill respirators treated with methylene blue and UV light failed the PortaCount fit test, despite there being no previously-identified issues with any of the respirators treated with these decontamination methods during the visual inspection. Finally, two of the five 3M 1870+ respirators and three of the five 3M 1860 respirators treated with dry heat failed the PortaCount fit test. It should be noted that one of the 3M 1870+ respirators treated with dry heat was deemed to have failed the fit test because its strap broke during donning (despite no visible signs of

damage prior to donning). Additionally, the respirator that was identified as having a damaged nosepiece was *not* one of the respirators to fail the PortaCount fit test.

3.2 Comfort assessment. Participants reported a number of physical changes and comfort changes among the decontaminated masks. Physical changes varied widely, but the areas of the face reported to be less comfortable while wearing decontaminated masks most often included the nose, chin and cheeks (see Table A1 in Appendix A).

3.3 General questionnaire. Concerns were reported in relation to protection from pathogens and contamination. Opinions on endorsements of decontamination methods varied, and mistrust in decontaminated masks was commonly reported. Responses to individual questionnaire items, parsed by study arm, are reported in Tables 2 and 3, below.

Table 2. General questionnaire responses for N95 respirator participants.

Anticipated Change in Ability to Perform Work	
No (n = 11) Maybe (n = 4) Yes (n = 0)	• Concerns about mask integrity (n = 2) • Concerns about fit (n = 3) • Concerns about comfort (n = 1)
Concerns About Pathogens Potentially Acquired During Previous Use	
No (n = 12) Maybe (n = 3) Yes (n = 0)	• Concerns about touching incompletely decontaminated masks during donning (n = 1) • Concerns about fit (n = 1) • Desire for more information about decontamination process (n = 1) • Desire for confirmation that decontamination was efficacious (n = 2)
Concerns About Pathogens from Current Patient	
No (n = 9) Maybe (n = 6) Yes (n = 0)	• Concerns about fit (n = 3) • Concerns about mask being damp (n = 1) • Concerns about filtration ability (n = 1) • Desire for more information about decontamination process (n = 1)
Concerns About Exposure to SARS-CoV-2	
No (n = 10) Maybe (n = 5) Yes (n = 0)	• Concerns about fit (n = 1) • Concerns about mask being damp (n = 1) • Concerns about filtration ability (n = 1) • Desire for more information about decontamination process (n = 1) • Desire for confirmation that decontamination was efficacious (n = 1)
Provided Information Useful in Event of PPE Shortage?	
No (n = 0) Yes (n = 15)	• Desire for confirmation that decontamination was efficacious (n = 2) • Desire for information about how decontamination efficacy determined (n = 1) • Desire for confirmation that decontaminated masks are as efficacious as new masks (n = 1) • Desire for confirmation of proper fit (n = 1) • Desire for more information about decontamination process (n = 2) • Desire for more information about chain of custody system (n = 1)

	• Desire for more information about mask history (e.g., number of prior uses) (n = 1) • Desire for more information in general (n = 1)
Trust in Masks	
VHP Trust: *M* = 81.89, *SD* = 13.77, Range 60 – 100, based on n = 9 (n = 4 3M 1870+, n = 4 3M 1860, n = 1 Halyard Duckbill) MB+UV Trust: *M* = 79.8, *SD* = 20.61, Range 28 – 100, based on n = 10 (n = 4 3M 1870+, n = 2 3M 1860, n = 4 Halyard Duckbill) DH Trust: *M* = 86.10, *SD* = 13.16, Range 69 – 100, based on n = 10 (n = 3 3M 1870+, n = 2 3M 1860, n = 5 Halyard Duckbill)	• Concerns about fit (n = 5) • Concerns about mask integrity (n = 1) • Concerns about comfort (n = 3) • Concerns about odor (n = 2) • Concerns about safety of odor source (n = 1) Note that *n* values above are summed across VHP, MB+UV and DH.

Contamination Concerns	
Self (n = 8) Family (n = 7) Friends (n = 5) Medical/Legal Liability (n = 3) Other (n = 2) No Concerns (n = 4)* *Two additional participants reported "no concerns" in combination with concerns related to "family" and "other", respectively.	• Concerns about protecting patients (n = 3) • Concerns about skill in performing hand hygiene and/or using PPE properly (n = 2) • Concerns about fit (n = 1) • Desire for more information about decontamination process and its efficacy (n = 1)
Chain of Custody System Integrity Concerns	
No (n = 8) Maybe (n = 6) Yes (n = 1)	• Concerns about the tracking process (n = 3) • Does not have enough information on chain of custody (n = 4)
Decontamination Process Concerns	
No (n = 7) Maybe (n = 6) Yes (n = 2)	• Concerns about chemicals involved in decontamination process, including their safety (e.g., contact, inhalation, prolonged exposure) (n = 2) • Concerns about decontamination efficacy (n = 2) • Concerns about mask integrity (n = 1) • Desire for information about how many reuse cycles masks can undergo (n = 2) • Desire for information about how decontamination efficacy determined (n = 2) • Concerns about packaging of decontaminated masks, storage, and preservation of decontamination prior to use (n = 2) • Does not have enough information on decontamination process (n = 4)
Concerns About Mask Structure and Function	
Structure (n = 2) Function (n = 5) Neither (n = 8)	• Concerns about airtight seal (n = 1) • Concerns with efficacy and/or integrity over time (n = 2) • Concerns about fit (n = 2) • Concerns about ease of donning a previously-worn mask (n = 1)
Need for Additional Information	
No (n = 5) Yes (n = 9)	• Desire for more information about decontamination process (n = 4) • Desire for information about how decontamination efficacy determined (n = 1) • Desire for more information about chain of custody system (n = 3) • Desire for information about how to inspect and assess decontaminated mask for integrity prior to use (n = 1) • Desire for confirmation of proper fit (n = 1) • Desire for more information about decontaminated mask efficacy (n = 1) • Desire for more information about how long decontaminated masks should be worn (n = 1) • Desire for more information about which masks are selected for decontamination (e.g., some vs. all previously used masks) (n = 1)
Safety Perceptions Positively Influenced by Acceptance/Endorsement	
…by Workplace?	No (n = 2) Yes (n = 13)
…by Health Canada?	No (n = 2) Yes (n = 13)
…by the FDA?	No (n = 4) Yes (n = 11)
…by the WHO?	No (n = 2) Yes (n = 13)
…by the Manufacturer?	No (n = 8) Yes (n = 7)

Except for the last row (*Safety Perceptions Positively Influenced by Acceptance/Endorsement*), the left column reports forced-choice responses, and the right column summarizes the negative themes (i.e., concerns, requests for more information, inability to make judgements) identified in participants' open-ended responses to the same questions.

Table 3. General questionnaire responses for non-N95 mask participants.

Anticipated Change in Ability to Perform Work	
No (n = 8) Maybe (n = 7) Yes (n = 0)	• Concerns about comfort (n = 1) • Concerns about fit (n = 2) • Concerns about odor (n = 1) • Concerns about efficacy (n = 1)
Concerns About Pathogens Potentially Acquired During Previous Use	
No (n = 8) Maybe (n = 6) Yes (n = 1)	• Concerns about decontamination process and/or its efficacy (n = 3) • Concerns about number of times mask reused (n = 1) • Concerns about chain of custody system (n = 1) • Concerns about systemic error (n = 1) • Does not have enough information to make a judgement (n = 1)
Concerns About Pathogens from Current Patient	
No (n = 6) Maybe (n = 6) Yes (n = 3)	• Concerns about decontamination process and/or its efficacy (n = 1) • Concerns about number of times mask reused (n = 1) • Does not have enough information to make a judgement (n = 1) • Would have concerns about fit if the mask were a FFR (n = 1) • "Don't feel comfortable" (n = 1)
Concerns About Exposure to SARS-CoV-2	
No (n = 8) Maybe (n = 4) Yes (n = 3)	• Concerns about decontamination process and/or its efficacy (n = 1) • Does not have enough information to make a judgement (n = 1) • More discomfort with SARS-CoV-2 than other pathogens (n = 1) • Concerns about any pathogens (not limited to SARS-CoV-2) (n = 1) • Concerns about aerosol-generating procedures with a FFR (n = 1) • "Not comfortable at all" (n = 1)
Provided Information Useful in Event of PPE Shortage?	
No (n = 5) Yes (n = 10)	• Desire for more information about decontamination process and/or its efficacy and/or its safety (n = 5)
Trust in Masks	
VHP Trust: *M* = 60.56, *SD* = 27.85, Range 9 – 95, based on n = 9 (n = 4 Halyard, n = 5 WHO) MB+UV Trust: *M* = 63.85, *SD* = 27.43, Range 1 – 96, based on n = 13 (n = 4 Halyard, n = 5 WHO, n = 4 Colorado) DH Trust: *M* = 60.93, *SD* = 31.32, Range 0 – 100, based on n = 14 (n = 4 Halyard, n = 5 WHO, n = 5 Colorado)	• Desire for more information about decontamination process (n = 6) • Desire for more information about safety (n = 3) • Not enough information about decontamination process to make a judgement (n = 3) • Concerns about odor (n = 1) • Concerns about fit (n = 4) Note that *n* values above are summed across VHP, MB+UV and DH.
Contamination Concerns	
Self (n = 8) Family (n = 4) Friends (n = 4) Medical/Legal Liability (n = 3) Other (n = 4) No Concerns (n = 4)* An additional participant reported having both no concerns and "other."	• Concerns about protecting patients (n = 1) • Concerns about exposure to chemicals from decontamination process (n = 1) • Concerns about decontamination efficacy (n = 1) • Concerns about mask efficacy (n = 1) • Concerns about exposure to microbes (n = 1) • Concerns about fit (n = 2) • Concerns about general process (i.e., decontaminating and reusing masks) and/or desire for more information (n = 3)

Chain of Custody System Integrity Concerns	
No (n = 11) Maybe (n = 2) Yes (n = 2)	• Desire for more information about chain of custody system (n = 1) • Concern about error (n = 2) • Does not have enough information to make a judgement (n = 1)
Decontamination Process Concerns	
No (n = 7) Maybe (n = 5) Yes (n = 3)	• Desire for more information about decontamination process and/or its efficacy and/or its safety (n = 5) • Desire for confirmation that masks returned to correct users (n = 1) • Does not have enough information to make a judgement (n = 1)
Concerns About Mask Structure and Function	
Structure (n = 6) Function (n = 2) Neither (n = 9)	• Concerns about fit (n = 2) • Concerns about thickness of fabric (n = 1) • Concerns about ear loop/straps (n = 2) • Concerns about extended wear (n = 1)
Need for Additional Information	
No (n = 2) Yes (n= 13)	• Desire for a FAQ (n = 1) • Desire for more information about decontamination process and/or its efficacy and/or its safety (e.g., the safety of the chemicals involved) (n = 7) • Desire for more information about the efficacy of decontaminated masks (e.g., filtration ability) (n = 2) • Desire for more information about how many times masks can be decontaminated and reused (n = 1) • Desire for more information about how masks are tracked (n = 1) • Desire for more information about history of masks (e.g., decontamination date) (n = 1)
Safety Perceptions Positively Influenced by Acceptance/Endorsement	
…by Workplace?	No (n = 6) Yes (n = 9)
…by Health Canada?	No (n = 4) Yes (n = 11)
…by the FDA?	No (n = 6) Yes (n = 9)
…by the WHO?	No (n = 4) Yes (n = 11)
…by the Manufacturer?	No (n = 7) Yes (n = 8)

Except for the last row (*Safety Perceptions Positively Influenced by Acceptance/Endorsement*), the left column reports forced-choice responses, and the right column summarizes the negative themes (i.e., concerns, requests for more information, inability to make judgements) identified in participants' open-ended responses to the same questions.

3.3.1 Protection from pathogens. Participants reported concerns about the efficacy of the decontamination methods in destroying pathogens, the criteria used to confirm that masks were effectively decontaminated or cleaned, the integrity of the masks following decontamination, and the number of reuses and duration of wear that the decontaminated masks could withstand. Many participants expressed a desire for more information in these areas.

3.3.2 Concerns about contamination. Concerns about contaminating oneself, one's friends and family were reported, as well as medical/legal liability concerns. Some participants additionally reported concerns about contaminating patients. However, some participants

clarified that they were concerned more about their own skill and ability to properly use the decontaminated masks, than the decontaminated masks themselves. Additionally, concerns related to the safety of the chemicals used in the decontamination process with respect to skin contact and inhalation (particularly with respect to repeated and prolonged wear) were reported.

Participants' concerns about the integrity of the chain of custody system (i.e., the decontamination and reuse system within their workplace) were primarily related to the tracking of masks throughout the process, including the ability of staff to clearly and correctly label their masks, the distortion or loss of mask labels during the decontamination process, the storage of decontaminated masks and the potential for recontamination following decontamination but prior to reuse, and general errors. A number of participants commented that they were unfamiliar with the chain of custody system and required more information before being able to make a judgement about chain of custody system integrity.

3.3.3 Endorsements. Most participants reported that acceptance or endorsement by their employer, Health Canada, the FDA or the WHO would positively influence their views on the safety of decontaminated masks in both arms of the study. However, acceptance and endorsement from the manufacturer appeared to be a polarizing subject for participants in the N95 respirator arm of the study. Some participants viewed acceptance and endorsement from the manufacturer as particularly trustworthy, given that the masks are intended to be single use and the manufacturer stands to gain the most from single use. Others perceived the manufacturer to have a conflict of interest and thus seemed to trust the manufacturer's acceptance and endorsement of a decontamination process to a lesser degree than those of third parties. A small majority of participants in the non-N95 mask arm of the study, however, reported that

endorsement from the manufacturer would positively influence their views on the safety of decontaminated masks.

3.3.4 Trust. When asked to rate their trust in the masks on a scale from 0 to 100%, participants rarely reported total trust in the decontaminated masks that they had been assigned to. Interestingly, this occurred even with decontaminated N95 respirators that had been demonstrated to perform to the same standard as new, not previously worn masks (see Table 2). Unfortunately, it is unclear whether participants who reported a lack of trust in the decontaminated masks could also have trust issues with new, unused masks. For example, one participant expressed concern about the efficacy of N95 respirators in protecting the wearer in general, particularly when speaking. Additionally, it was noted that participants had a difficult time using the slider scale, which could have introduced error into the quantitative ratings of trust provided by participants. Qualitatively, however, a number of concerns that negatively affected trust were reported. These concerns included not knowing enough about the decontamination method, and its safety and efficacy; a general unease with masks that had been previously worn; awareness of studies that demonstrated a negative effect of decontamination on fit; perceived differences in the feel of the mask on the face that were suspected to have a negative effect on fit, comfort and dermatological conditions; and, concerns about the odor, including its cause and potential to harm the wearer over time.

4. Discussion

We sought to identify any physical or psychological sources of discomfort that could negatively affect work performance while using decontaminated masks on the front lines of healthcare. Our qualitative analysis suggests that decontaminated masks were generally

perceived to be less physically comfortable, less trustworthy, less acceptable and less safe than new, untreated and not previously worn masks.

First, physical differences between decontaminated masks and untreated masks were reported by participants. Many of these physical differences translated into unpleasant experiences for wearers. Vision, communication and comfort problems were all identified among decontaminated masks within our study. This observation is particularly interesting with respect to the N95 respirators. Because questions related to physical feel and comfort were only asked for respirators that were found to successfully fit participants, it appears that the preservation of fit does not necessarily imply the preservation of comfort.

In addition to physical and comfort differences, it was clear that participants felt uneasy about decontaminated masks, even when they fit properly. Some participants had reservations, concerns and distrust of decontaminated masks, even with N95 respirators to which they had been successfully fitted. The extent to which reported differences in comfort and user acceptance might be an artifact of participants' bias toward the reuse of masks is unknown. Although it is unclear if differences in comfort and negative perceptions of decontaminated masks would occur in a blinded test, where participants were made unaware of either the results of the fit test or the type of mask (i.e., treated or untreated), we feel that it is a moot point. Pragmatically, real-world users will almost certainly be aware of whether a mask provided to them as part of their work has been previously used. Our findings suggest that it is important to understand HCWs' perceptions of comfort and user acceptance within that context. PPE discomfort was identified as a barrier to PPE use during both the current pandemic and during the SARS outbreak (Moore et al., 2005; Tan et al., 2006; Chu et al., 2020), and it has been reported to have a workload cost (Moore et al., 2005). When considering the feasibility of different decontamination methods for the purposes of

mask reuse, HCWs' discomfort – in terms of both physical and psychological concerns – should be taken seriously and considered in the decision to implement any particular method.

Many participants were concerned about the decontamination methods, including their efficacy in destroying pathogens, their efficacy in protecting the wearer and those around them, and the safety of the chemicals involved. The importance of providing clear information about the efficacy of decontaminated masks in protecting the wearer and those around them cannot be understated: perceptions of efficacy can mitigate against other perceived barriers to PPE use, including discomfort (Tan et al., 2006). Moreover, some participants had concerns about the chain of custody system, such as the potential for tracking errors and recontamination. The efficacy of a decontaminated mask in protecting the wearer and those around them was, for some HCWs, related to their trust in the integrity of the decontamination and reuse system rather than in the decontamination method itself. Given the wide variety of important issues that our interviews with HCWs identified, which may be unique to our participant population, we recommend involving HCWs during consultations about the implementation of mask decontamination and reuse procedures in healthcare settings. Focus groups may be useful in identifying sources of concerns, discomfort and distrust, from the moment the mask is removed from the face during its first wearing to the moment that it is placed in the hands of the next user for its second wearing. Some of these concerns could be remedied through clear communication and training. Finally, based on participants' comments within this study, we additionally recommend that decontamination and reuse systems should incorporate feedback channels, and HCWs should receive training in accessing and using them. For example, one participant expressed concerns about the provision of appropriate writing implements to apply tracking markings to the used masks. The ability to make that feedback known and acted upon within the

system could serve not only to maintain or enhance integrity within the system, but also HCWs' trust in the system.

4.1 Limitations. A number of limitations to our study warrant discussion. First, due to the small number of respirators and surgical/procedural and community cloth masks available for use in the study, only 30 masks were available to function as untreated controls, and it was not always possible to replace masks that failed to fit participants. Due to our small supply, participants were required to interact with one untreated control mask and three treated masks in a repeated-measures design. For the visual inspection and comfort assessment components, participants were asked to make relative judgements, which may have led to recall bias. We presented decontaminated masks in a random order to prevent working memory-related order effects. However, based on our results, fit test failures and successes within the study did appear to influence participants' judgements in the general questionnaire. For example, when participants were asked if they thought that decontaminated masks would change their ability to work, or about their perceptions of the ability of decontaminated masks to protect the wearer from newly-encountered pathogens, concerns raised by those who had them were often related to the masks with which they had interacted as part of the study. Because the PortaCount fit testing machine directed participants through the subtests with a graphical user interface that simultaneously presented the results of the fit tests in real time, the participants were not blinded to the results of the PortaCount fit tests and were aware of successful fits and failures. Two participants explicitly referred to the results of their PortaCount fit tests during the study session. The first participant, who experienced a fit test failure, expressed concerns about the ability of decontaminated masks to maintain their fit over time. However, the second participant, who did not experience any fit test failures, reported that their experience in the study led them to deem

decontaminated masks as safe. In fact, the latter participant reported wondering whether "breaking in" a mask via reuse could be beneficial for fit.

Next, frequent fit-test failures led to data loss in the comfort assessment components of the study. The general guideline for usability studies is to recruit five representative users for each representative user group (Nielsen, 2000). Although we recruited five representative users for each of the 24 study conditions, which is consistent with Nielsen's (2000) advice, data loss occurred in the comfort assessment component of the N95 respirator arm of the study. The purpose of our study was to assess potential differences in physical appearance, comfort and user acceptance *despite* preservation of fit among decontaminated masks, and we did not always have access to additional masks to replace lost data when masks failed to fit participants in our study.

Unfortunately, as previously discussed, we discovered quality control issues with the shoelace-like strap design of the handmade Colorado cloth masks. Due to subtle differences in construction and the need for participants to tie the straps in a knot behind the head, some of the reported differences in physical fit and comfort among the decontaminated Colorado cloth masks may be due to inconsistent mask shape and inconsistent donning practices.

Another limitation of our study stems from the fact that masks and N95 respirators had not been worn prior to decontamination. In the real world, masks would have been worn for a period of time before undergoing decontamination to prepare them for reuse. A recent study involving decontamination and reuse of N95 respirators following actual wear in a Canadian hospital demonstrated that respirator fit was not as robustly preserved when subjected to repeated autoclaving cycles compared to previous studies involving unused respirators (Czubryt et al., 2020). The physical appearance, comfort, and preservation of proper fit following both repeated wear in clinical environments and the decontamination methods employed in our study remain

unknown. We also recognize that our findings may not be generalizable to other settings and countries with differing HCW populations and where perceptions may be different.

Finally, we asked participants to make judgements about how they might feel in hypothetical situations. These judgements do not necessarily translate into real-world behaviour. To understand how HCWs use decontaminated masks, how that use affects performance, and whether the recommendations we make here are effective in improving performance and reducing discomfort and distrust, a follow-up observational study is required.

5. Conclusion

The results of our qualitative analysis indicate that concerns, reservations and discomfort are likely to occur when decontaminated masks are introduced during PPE shortages. HCWs' concerns should be addressed with the provision of clear information including the nature of the decontamination method, its efficacy in destroying pathogens, the efficacy of the mask in protecting the wearer and those around the wearer, and the nature and integrity of the broader mask decontamination and reuse system. However, information needs may vary from population to population, and we recommend involving HCWs in decontamination and reuse policy planning to ensure that those needs are addressed.

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Declaration of interests

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

JMC is a co-principal investigator for a study funded from the Canadian Institutes for Health Research on acute and primary care preparedness for COVID 19 in Alberta, Canada and was the primary local investigator for a *Staphylococcus aureus* vaccine study funded by Pfizer for which all funding was provided only to the University of Calgary. He is a co-investigator on a WHO funded study using integrated human factors and ethnography approaches to identify and scale innovative IPC guidance implementation supports in primary care with a focus on low resource settings and using drone aerial systems to deliver medical supplies and PPE to remote First Nations communities during the COVID 19 pandemic. He also received support from the Centers for Disease Control and Prevention (CDC) to attend an Infection Control Think Tank Meeting. He is a member and Chair of the WHO Infection Prevention and Control Research and Development Expert Group for COVID 19 and a member of the WHO Health Emergencies Programme (WHE) Ad hoc COVID 19 IPC Guidance Development Group, both of which provide multidisciplinary advice to the WHO, for which no funding is received and from which no funding recommendations are made for any WHO contracts or grants. He is also a member of the Cochrane Acute Respiratory Infections Group.

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Declarations of interest for all other authors: none.

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Appendix A

Table A1. Physical and comfort differences reported for decontaminated masks (relative to untreated masks).

Vaporized Hydrogen Peroxide		
3M 1870+ FFR (*n* = 4)	3M 1860 FFR (*n* = 4)	Halyard Duckbill FFR (*n* = 1)
Physical Differences • less-secure fit around nose (*n* = 1) • less-secure fit around chin (*n* = 1) • a "lighter" feeling in terms of stability (*n* = 1) • looser straps (*n* = 1) • odor (*n* = 2) *Comfort Differences* • increased discomfort on both nose and chin (*n* = 1)	*Physical Differences* • less-secure fit on nose (*n* = 1) • increased pressure on nose (*n* = 1) • stiffer straps (*n* = 1) • odor (*n* = 3) *Comfort Differences* • increased discomfort on chin (*n* = 1) • increased discomfort on both nose and cheeks (*n* = 1)	*Physical Differences* • less-secure fit around the nose (*n* = 1) *Comfort Differences* • increased discomfort on the nose (*n* = 1)
WHO S/P (n = 5)	Halyard S/P (n = 5)	Colorado Cloth Mask (n = 0)
Physical Differences • looser fit on nose (*n* = 1) • poorer fit with upward slipping (*n* = 1) • decreased stability (*n* = 1) • odor (*n* = 2) *Comfort Differences* • increased discomfort on chin (*n* = 1)	*Physical Differences* • tighter on nose (*n* = 1) • better fit on nose* (*n* = 1) • better fit, more coverage on the chin* (*n* = 1) • increased difficulty seeing over mask (*n* = 1) • more pressure on face, snugger and tighter feel (*n* = 2) • increased stability (*n* = 2) • decreased stability (*n* = 1) • tighter elastics, more comfortable (*n* = 1) • thinner feel, more movement (*n* = 1) • odor (*n* = 2) *Comfort Differences* • increased discomfort on nose (*n* = 1) • increased discomfort on nose and cheeks (*n* = 1)	(none)
Methylene Blue and UV Light		
3M 1870+ FFR (*n* = 4)	3M 1860 FFR (*n* = 2)	Halyard Duckbill FFR (*n* = 4)

Physical Differences • difference in fit around nose (wire nosepiece required adjustment because it was previously unfolded prior to decontamination) (*n* = 1) • looser fit on chin (*n* = 2) • decreased stability on face (*n* = 2) • looser elastics (*n* = 1) • "crisper" texture (*n* = 1) *Comfort Differences* • increased discomfort on the chin and cheeks (*n* = 1) • increased discomfort on nose (*n* = 1) • increased discomfort on chin (*n* = 1)	*Physical Differences* • change in ability to see over mask due to increased difficulty molding nosepiece (*n* = 1) *Comfort Differences* • increased discomfort on nose (*n* = 1)	*Physical Differences* • tighter elastics (*n* = 1) • odor (*n* = 1) *Comfort Differences* • increased discomfort on nose (*n* = 1)
WHO S/P (n = 5)	Halyard S/P (n = 5)	Colorado Cloth Mask (n = 5)
Physical Differences • difference in pressure on face (*n* = 1) • less stable, more movement (*n* = 1) *Comfort Differences* • decreased comfort on nose (*n* = 1)	*Physical Differences* • looser fit on nose (*n* = 2) • more movement on chin (*n* = 1) • shift upward toward the eyes (n = 2) • less stable, more movement (*n* = 1) • looser elastics (*n* = 2) • odor (*n* = 1) *Comfort Differences* • decreased comfort on chin (*n* = 2)	*Physical Differences* • crooked fit on nose (*n* = 1) • better fit on nose (*n* = 1) • worse fit on nose (*n* = 1) • snugger fit on chin (*n* = 1) • looser fit on chin (*n* = 1) • less "warm" on the face due to difference in pressure (n = 1) • increased stability (*n* = 1) • decreased stability (*n* = 1) • more "rugged" texture (*n* = 1) • less comfortable texture (*n* = 1) • odor (*n* =1) *Comfort Differences* • decreased comfort on chin and back of head (*n* = 1)

Dry Heat		
3M 1870+ FFR (*n* = 3)	3M 1860 FFR (*n* = 2)	Halyard Duckbill FFR (*n* = 5)
Physical Differences • "stiffer," "scratchier," "crisper" texture (*n* = 1) • odor (*n* = 1) *Comfort Differences* • decreased comfort on cheeks (*n* = 2)	*Physical Differences* • less accommodating of glasses (*n* = 1) • tighter elastics (*n* = 1)** *Comfort Differences* • (none)	*Physical Differences* • difficulty achieving good fit on nose (*n* = 1) • tighter on nose (*n* = 1) • less secure on chin (*n* = 2) • less stable on face (*n* = 3) • tighter elastics (*n* = 1) *Comfort Differences* • decreased comfort on chin (*n* = 1) • decreased comfort on nose and back of head (*n* = 1)
WHO S/P (n = 5)	Halyard S/P (n = 5)	Colorado Cloth Mask (n = 5)
Physical Differences • odor (*n* = 2) *Comfort Differences* • decreased comfort on nose (*n* = 1)	*Physical Differences* • looser fit on nose (*n* = 3) • larger gap around chin (*n* = 1) • more movement on chin (*n* = 1) • obscured vision (*n* = 1) • less stable on face (*n* = 3) • looser elastics (*n* = 1) • thinner texture (*n* = 1) • odor (*n* = 1) *Comfort Differences* • decreased comfort on lips (*n* = 1) • decreased comfort on nose and cheeks (*n* = 1) • decreased comfort on chin and cheeks (*n* = 1)	*Physical Differences* • different fit on nose (*n* = 1) • better fit on nose (*n* = 1) • bigger on chin (*n* = 2) • more stable on face (*n* = 1) • odor (*n* = 1)*** *Comfort Changes* • decreased comfort on chin (*n* = 1)

*Participant reported this may have been due to increased attentiveness during donning.

**Participant was unsure if this was a general aspect of all 3M 1860 FFRs.

***Participant was unsure if the mask had a *different* odor than the other two.